Trends in Use of the Computer Assisted Instruction in Biological Sciences Education: A Systematic Literature Review

Jean Jacques Munyemana*, Florien Nsanganwimana, and Gaspard Gaparayi

***Abstract*—The usage of computers is gaining popularity in science education specifically in biology education. The topic concerning Computer Assisted Instruction (CAI) materials is one of the topics covered in biology education research. Where they are reportedly to have an impact on the academic achievement of the students. In this review, published peer reviewed scientific literature on computer usage in biological science instruction was analyzed to answer the questions relating to the kind of computer applications commonly used as computer assisted instruction in biological science education. Biological topics mostly taught using computer assisted instruction. As well, as the learning outcomes commonly measured when studying computer applications in biological science education. The results from the analyzed literature show that web applications are the most used computer technologies. These applications are mostly designed and developed by researchers. The visual displays mostly used are computer-based animation, while Biochemistry and Photosynthesis specifically are biology topics covered. The learning outcome targeted is academic achievement. Though these reports showed a positive impact on learning outcomes, many works are still needed specifically the use of modern technologies such as virtual reality (AR) and augmented reality (AR), in the biology teaching and learning process.**

***Index Terms*—Computer assisted instruction, biology, teaching and learning, ICT, Academic achievement, visual display**

I. Introduction

In the 21st century, we are edging through a technological revolution, which affects every aspect of human life. The use of computers in education is gaining popularity. Computers have been used in science education for more than a decade [1]. The usage of computer technologies in instruction is called computer assisted instruction (CAI) or computer based instruction (CBI) or computer assisted learning (CAL). CAI involves interactive instructional techniques whereby a computer is used to present the content. CAI may be offline or online with programmed instructional material. Most CAIs are used adjunctively with other sources of knowledge [2].

Computer Assisted Instruction (CAI) has been used for quite a long time [3]. By the late 1950s, early computers were available and promised to offer an alternative better for teaching machines than mechanical devices. However, it required to wait until the 1980s when there was a global interest in the computer as teaching material. These early applications of computers to education were mostly demonstrations to show the potential use of computers in education. Researchers built on Skinner's work and used mathematical models of student learning to design instructional materials and learning strategies to achieve a level of individualization. The early computer based teaching system to enter commercial production was the Self-Adaptive Keyboard Instructor (SAKI), developed by Gordon Pask and Robin McKinnon-Wood in 1956. Further developments were then made developments in programmed instruction (CAI) arise from perspectives influenced by behaviorism and cognitive science. While teachers have mostly used CAI for drill and practice, especially in teaching mathematics and languages, there have been other users of CAIs as well [4, 5].

There are numerous types of CAI reported in the literature. These are drill and practice which provides opportunities for students to repeatedly practice the skills that have previously been presented. Tutorials include both the presentation of information and its extension into different forms of work. A simulation which involves software that can provide an approximation of reality, that does not require the expense of real life or its risk. Critical thinking and enrichment, which helps children, develop specific problem solving skills and strategies. Computer based laboratories. These involves discovery approach that provides a large database of information specific to a course or content area and challenges the learner to analyze, compare, infer and evaluate based on their explorations of the data. Integrated learning systems, are made up of two components: computer aided instruction (CAI) modules (often called courseware) and a management system to manage the learning. The learning management systems are more recent innovations [5].

The advantages of CAI include stimulating students' interest in the subject content, improved academic performance as well as students' motivation. Other advantages include but are not limited to being naturally modular, which makes it easy to revise as the situation change. CAIs are Self-administered therefore they are available on call. CAI provides feedback immediately or delayed which assists in reinforcement and motivation of the students. The programming nature of CAI allows controlled access and interactivity.

The disadvantages of CAI include but are not limited to a programmer cannot cater for every possible response and may give unexpected and unhelpful responses to unusual input. A few students are intimidated by the strangeness of a computer terminal. Packages can become boring if a student

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is alone at a terminal for too long. Most packages should run for an hour or so. A package will not be appreciated unless it has a perceived goal and will not be considered important unless it is integrated into a course to the extent of being assessed by a teacher [6]. Though CAIs possess some limitations, they are still effective in improving teaching and learning processes.

Over a long time, there has been much change in science education, specifically in biology education towards better teaching and learning of biology concepts. Amongst changes done so far, there include teaching methods changed from teacher-centered to learner-centered. The teaching methods such as case-based, problem-based, project-based, concept mapping, and group works interactions were reported to have a positive effect on students' content retention and biology performance [6–10]. On the side of instructional materials, computer assisted instruction (CAI) materials are gaining popularity. And it was one of the topics covered in biology education research [7], where it was shown that these CAI have a high effect on the achievement of the students.

A. Objective and Research Questions

This study aims to undertake a review of published scientific literature on computer usage in biological science instruction.

This involves locating, classifying, and analyzing research conducted on the topic. This study concentrates on describing peer-reviewed journal articles on the topic, and answers the following questions:

1) What kind of computer applications are commonly used as computer assisted instruction in biological science education?
2) What biological topics are mostly taught using computer assisted instruction?
3) What are the outcomes commonly measured when studying computer applications in biological science education?

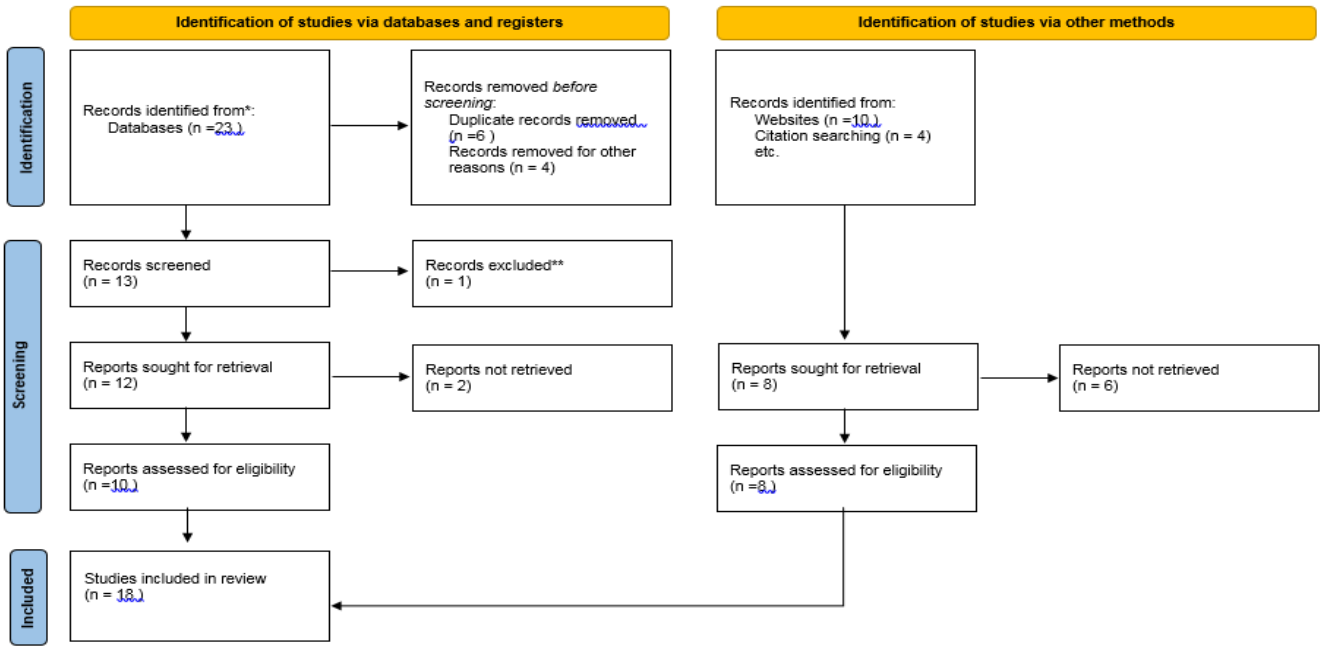

Fig. 1. PRISMA flow chart followed while selecting sources analysed in this review.

II. Methods

Materials(articles) were selected by applying the method presented by Terrell and Listenberger [11], for systematic reviews and PRISMA whose flowchart is presented in the Fig. 1. Peer-reviewed journal articles were identified and analyzed by using a consistent search strategy along with established criteria for selection of articles as presented in Table I. Using these keywords, a common search strategy was developed for the various databases consulted, adapting it to the characteristics of the given platform. For each database, a hierarchical search strategy was applied, starting from the most complex form to the simplest expression, to retrieve documents from all databases. Depending on the requirements of each database, the search fields were limited to the title and abstract of the documents, with consideration of all those published until 2019. In each database, various refined search strategies were employed for consistency purposes, such as solely locating peer-reviewed papers. After obtaining the document records, those to be analysed were identified. Search engines like google scholar and scientific databases such as ERIC, Google Scholar, BiomedCentral, and Scopus were used to search for articles. The search was done by using terms related to computer assisted learning, Computer assisted instruction, ICT in education, computer animation, computer based, multimedia, virtual, and biology education. The search was carried out in English language. The articles analysed are summarized in the Table II.

TABLE I: Criteria for Sources Selection

Scope	National and international
Research types	Empirical research on ICT or computer integration in biological science education
Journal	Peer reviewed
Period	Preferably 2010-2019
Targeted group	Students in secondary schools and undergraduate university students
language	English

TABLE II: ANALYZED SOURCES AND JOURNALS

Journal name	Analyzed sources
Biochemistry and Molecular Biology Education	[8] [9] [10] [12] [13] [14] [15] [16]
Computers and education	[17]
Structure 25	[18]
Education sciences	[19]
Cell biology education	[20]
Cypriot Journal of Educational Sciences	[21]
Procedia - Social and Behavioral Sciences,	[22]
South African Journal of Education	[23]
CBE—Life Sciences Education,	[24]
The Turkish Online Journal of Educational Technology	[25]
Зборник Института За Педагошка Истраживања Годин	[26]

The study used a qualitative survey with features of quantitative. Data were extracted and analyzed by qualitative content analysis and data were presented using graphs. Inductive content analysis was used to analyze types of computer technologies commonly used as CAI Deductive content analysis was used for biology topics and learning outcomes. Those paragraphs referring to CAI and learning outcomes were selected from the documents to determine the units for analysis.

III. RESULTS AND DISCUSSION

A. Types of Computer Applications Mostly Used as CAI in Biological Sciences Education

Computers are used to enhance learning, in most cases, computer applications are created by the authors themselves with a helping hand of a software engineer [27]. Microsoft Office PowerPoint is the easiest application used as Computer assisted instruction. This is probably because of its ease use, and does not require many technical skills to manipulate it, in addition to being used as standalone instructional modes. Some of these applications are web-based and online others are offline. computer technologies used to create these applications are programming languages such as HTML [25] and sometimes applications such as Avogadro Version 1.1.1, Protein Data Bank, 3D printing technologies, Macromedia dreamweaver, and many more [26, 28, 29].

According to data reported in the Fig. 2, web applications are still the most platform used according to reports analysed. They are said to be advantageous in decreasing the percentage of virus infection, facilitating the user's work of browsing and dealing with the site as well as to being accessible from any device connected to the Internet. Internet being the most used technology nowadays, it gives us many opportunities and has a very important impact on education today, to the extent that it is impossible to imagine education without it nowadays [30]. This explains why web based applications are the most used platforms, they appear that improve the state of education, making students more independent and helping them to educate themselves. These apps are advantageous in being compatible with any device such as a smartphone, tablet, laptop and personal computer in addition to their capability to be used as Cognitive; Practical; Attitude, and Assessment Apps. categories which constitute the aspect of the teaching process [31]. They Other platforms used were Microsoft powerpoint, web-based databases, media manipulating platform such as computer animation, 3D visualization, and adobe photoshops.

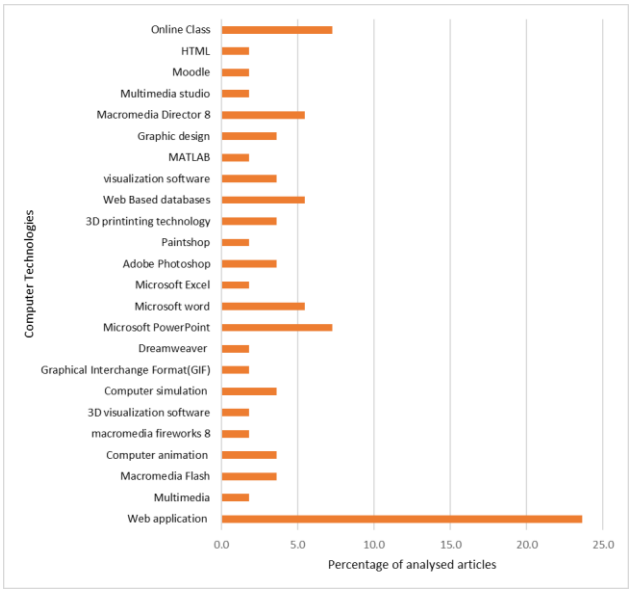

Fig. 2. Computer technologies reported in the analyzed sources.

B. Source of Computer Tools

Researchers and educators have developed their own computer applications mostly in the form of interactive multimedia CD-ROM [27]. However, there are some cases where biology educators adopt readymade materials. Fig. 3 summarizes the findings from the analysed articles.

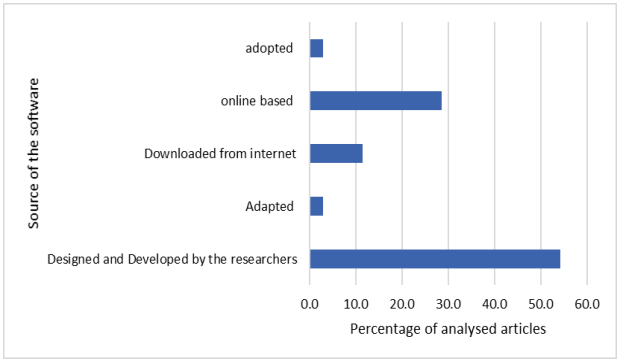

Fig. 3. Source of the computer software reported in the analysed reports.

Results from reported researches show that most computer materials are developed by the researchers themselves. Most CAIs are developed by educators with the helping hand of a software engineer. For the first time, teachers can easily modify and even produce their own CAI material based on the needs of their classes [32]. There is still a gap where teachers do not engage in developing CAI tools, instead, they adapt what others have developed, or simply download these tools from the internet. The advantage of adopting, adapting, or downloading computer tools is that it reduces the process

of developing own computer tools. However, the inability of teachers to develop their own computer based materials may contribute to the ineffective use of computer tools during instruction due to the missing of contextual experience. Because designing and developing CAI or ICT based materials are generally based on the intuition of the developer, such as the preferences, predispositions, and experiences of the designer [33]. Such development is addressing the identified issues [32]. Additionally, teachers' lack of ICT and computer skills may be the problem still hindering the effective use of computer based materials. The question remains whether biology teachers can design and develop computer based tools. Another challenge is to see whether what is found in research is transferred or practiced in the regular teaching and learning process. Further researches are necessary to verify this.

C. How Information Is Displayed

It has been said that visual displays are often said to enhance cognitive function [34] therefore when it comes to the development of a computational learning resource, the emphasis should be on the proper visual display of the content to be learned. Computer-based learning resources are designed to visually display Information in the form of 2D and 3D animations, 3D visualization, interactive exercises, and virtual laboratories to enhance students' understanding. Fig. 4 shows the summary of the visual displays reported in the analyzed articles.

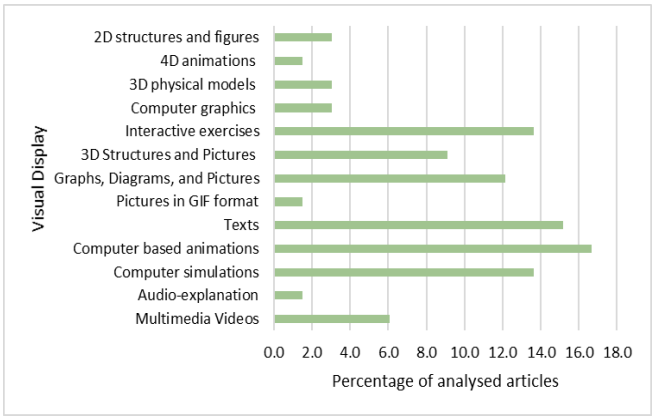

Fig. 4. visual display reported in the analyzed articles.

Nowadays with advances in computer graphics and human–computer interaction techniques, educational researchers and teachers use computers to develop dynamic interactive visualizations to teach students about scientific processes [34]. It is in that perspective most analyzed articles presented computer-based animations as a visual displays. Other visual displays reported in the analyzed literatures are computer simulations, interactive exercises 3D structures, and multimedia videos which falls under complex display types of visual display [34]. Nowadays advances in information technologies have led to new challenges in how to visualize large and complex data sets with researchers in scientific visualization focusing on displays of spatially distributed data and researchers in information visualization focusing more on visualization of abstract information spaces.

The advantages of such visual displays include but are not limited to allowing the storage of information externally by freeing up working memory resources for other aspects of thinking. Organizing information where information that is related is a natural property of iconic displays is grouped and also allows the offloading of cognitive processes onto perceptual processes [34]. It can be said that all the visual displays reported are conceived with the purpose of making learning more effective.

D. Biology Topics Mostly Thought Using Computer Assisted Instruction

Various biology subjects were taught using CAI. Fig. 5 shows biological subjects reported in the analyzed articles

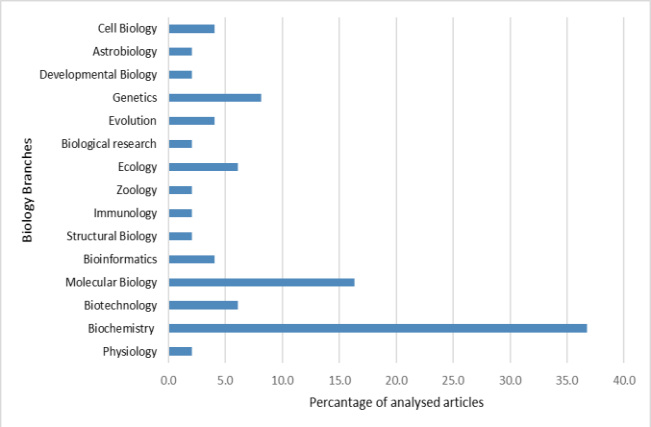

Fig. 5. Biology branches reportedly to be taught using CAI in the analyzed article.

Biochemistry and molecular biology are the most biology branch covered according to the research studies analysed. Biochemistry is a science that is investigated within the macroscopic, microscopic, and particularly, submicroscopic (molecular) levels of organization. Therefore for a holistic understanding of biochemistry, students are required to readily translate between these three levels of organization, something that can be rather difficult and confusing for them. Biochemistry is naturally a visual science comprising many abstracted concepts. These explain why it is the most biology branch taught using ICT tools which mostly are for visualization purposes. It is agreed that visualization tools are essential for understanding and researching molecular and cellular biosciences. Such tools are collectively termed external representations (ERs)1by cognitive psychologists [32]. Because they portray phenomena in the external world, contain spatial relationships, and can be distinguished from internal representations (e.g. mental models), which are an archetype of the mind [28]. Sound ERs, therefore, enable learners and researchers to construct meaningful mental models of biochemical phenomena, which allows for the visualization, integration, and understanding of biochemical concepts [29].

Fig. 6 shows that biology concepts covered are mostly biochemistry concepts where photosynthesis is the most biology topic taught using computer-based resources. Munyemana and Nsanganwimana *et al.* [35] reported that photosynthesis is the topic taught by using the computer where the resources are used simulation videos downloaded from the internet. It is said that Biochemistry being naturally

a visual subject, requires students to develop an understanding of numerous representations [36]. The interdisciplinary nature of biochemistry concepts poses a challenge to students to grasp the concept. This is due to the fact that the topic deals with numerous concepts from different scientific disciplines [37]. This explains why most concepts reported our biochemistry. It is from that perspective, researchers have been trying to use computer-based tools such as simulations and animations, to improve students' understanding of such concepts of photosynthesis [17, 23, 28, 38].

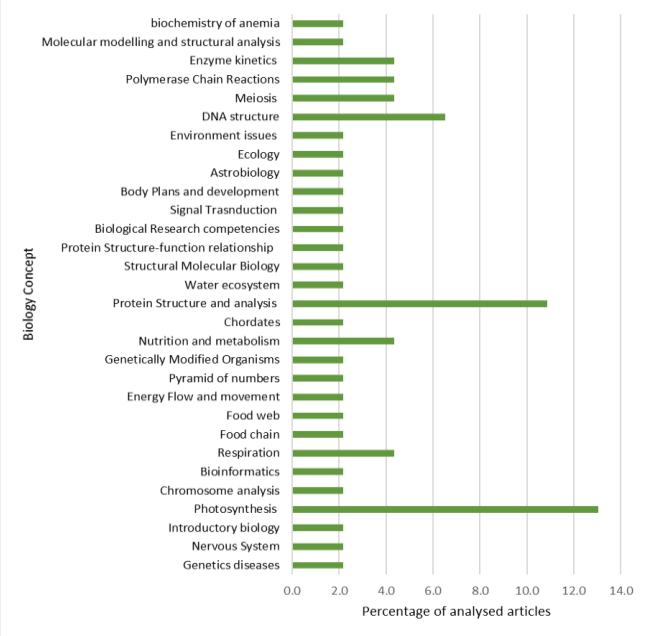

Fig. 6. Biology concepts reportedly to be taught using CAI in the analyzed articles.

IV. Learning Outcomes That are Mostly Measured

Fig. 7 shows the learning outcomes reported in the analyzed articles. Amongst the learning outcomes reported in the analyzed articles include but are not limited to academic achievement, understanding structures misconceptions, and many more.

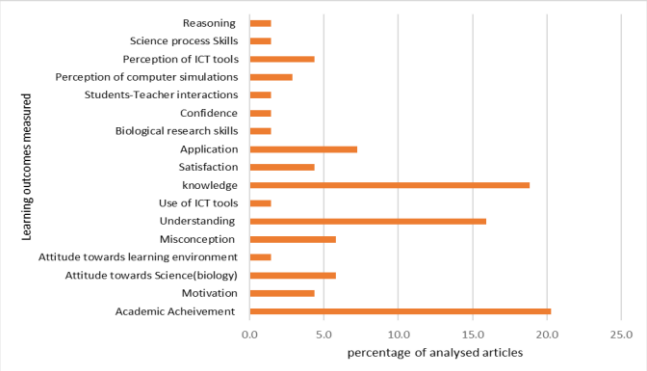

Fig. 7. Learning outcomes reportedly to be measured while teaching using CAI in the analyzed articles.

Data presented in Fig. 6 shows various learning outcomes most measured while teaching using CAI. The most outcome reported is academic achievement. Computer assisted instruction has been eportedly to have a positive effect on the academic achievement of students in biology. Hegarty [34] an experimental study analyzed the effectiveness of Computer-Assisted Learning (CAL) and the traditional teaching and learning method in biology. They found that the students exposed to CAL achieved higher both quantity and quality of knowledge in all three cognitive domains than the students from the traditional group. Similar results were observed, as reported by Russell and Netherwood *et al.* [39], whereby they observed an improved understanding of the basic concepts of photosynthesis by the students. Yusuf and Afolabi [25] found that the students exposed to CAI either individually or cooperatively performed better than those exposed to conventional classroom instruction. In a study aimed at Evaluating Biology Achievement Scores in an ICT integrated (Problem Based Learning) PBL Environment, Osman and Kaur [40] found that the ICT integrated with PBL group scored the highest compared to the PBL group and control group, the researchers realized that the integration of ICT elements marked the difference. Eckhardt and Urhahne *et al.* [19] also reported that the performance of students who attended Computer Aided-Structured interactive session (CA_SIS) was significantly inferior to their counterparts attending SIS using conventional tools. However, all the students wanted such CA-SIS again in the future, and all liked the CA-SIS and the website. Kareem [41] found that the introduction of computer-assisted instruction into senior secondary school improves students' academic achievement in biology. The integration of ICT tools in teaching and learning the biological subjects is tipped to increase students' understanding of the concepts and hence the increased academic performance.

Biology is a visual science comprising numerous structures which some are visually difficult to understand. Therefore using CAI can enhance students' understanding of such structure. Abreu and Carvalho *et al.* [16] reported that learning proteins and DNA structures using computational tools such as PDB and Swiss PDB Viewer (SPDBV) improved their performance and students in their contended the use of these computer applications in learning Deoxyribonucleic Acid (DNA) and protein structures is vital since they believed it could help in understanding the theory and make the learning process easier. The authors argued that this strategy is effective since it allows the contextualization of biochemistry themes and may complement theoretical classes.

Students' attitude toward science specifically biology is also another important learning outcome reported in the literature. Learning using CAI showed that students develop a positive attitude and motivation to study the subject. A study to compare online students and in-person students who completed astrobiology courses, Nugultham [31] found that online programs had more positive Attitudes towards Science compared to their traditional and in-person programs counterparts. Similarly, V égh and Nagy *et al.* [42] examined the efficacy of using the Edmodo interface within biology education in high schools, and they found that the Edmodo and ICT usage as facilitative tools, enhance students' academic performance as well as motivation in biology.

V. Conclusion And Recommendation

Research reports analyzed showed that various forms of CAI have been developed mostly by the researchers themselves and others were adopted,and all were reportedly to have a strong effect on the targeted learning outcomes.

However, studies are still needed to see whether biology teachers/ educators can make their own CAI tools to contextualize their teaching and learning processes. Another issue resides on the side of actual use of CAI in biology teaching and learning. Further research can be carried out to evaluate biology teachers' levels of usage of CAI in the teaching and learning process.

CAI tools should offer options for the user to process information as thoroughly as possible in order to achieve the best results. It is in that perspective the reported CAI was developed with a special focus on visual display mostly in the form of 2D, 3D, as well as 4D displays. Though these displays affect mental process in terms of information processing, many works are still needed specifically the use of modern technologies such as virtual reality (AR) and augmented reality (AR). These technologies may increase the efficacy of CAI since such technologies may increase the mental processing of information and hence allow long-term memory of the information.

In order to achieve the optimal results if CAI usage in teaching and learning, appropriate teaching and learning strategies are to be taken into consideration by teachers.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Jean Jacques Munyemana designed and conducted the research and wrote the paper; Florien Nsanganwimana and Gaspard Gaparayi approved the research design. All authors analyzed the data and approved the final version.

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